Vol. XXXVI. DECEMBER, 1896.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

No. 786.

IMPROVING THE ENTRANCE TO A BAR HARBOR BY A SINGLE JETTY.

By T. W. SYMONS, M. Am. Soc. C. E.

PRESENTED AT THE ANNUAL CONVENTION, 1896.

WITH DISCUSSION.

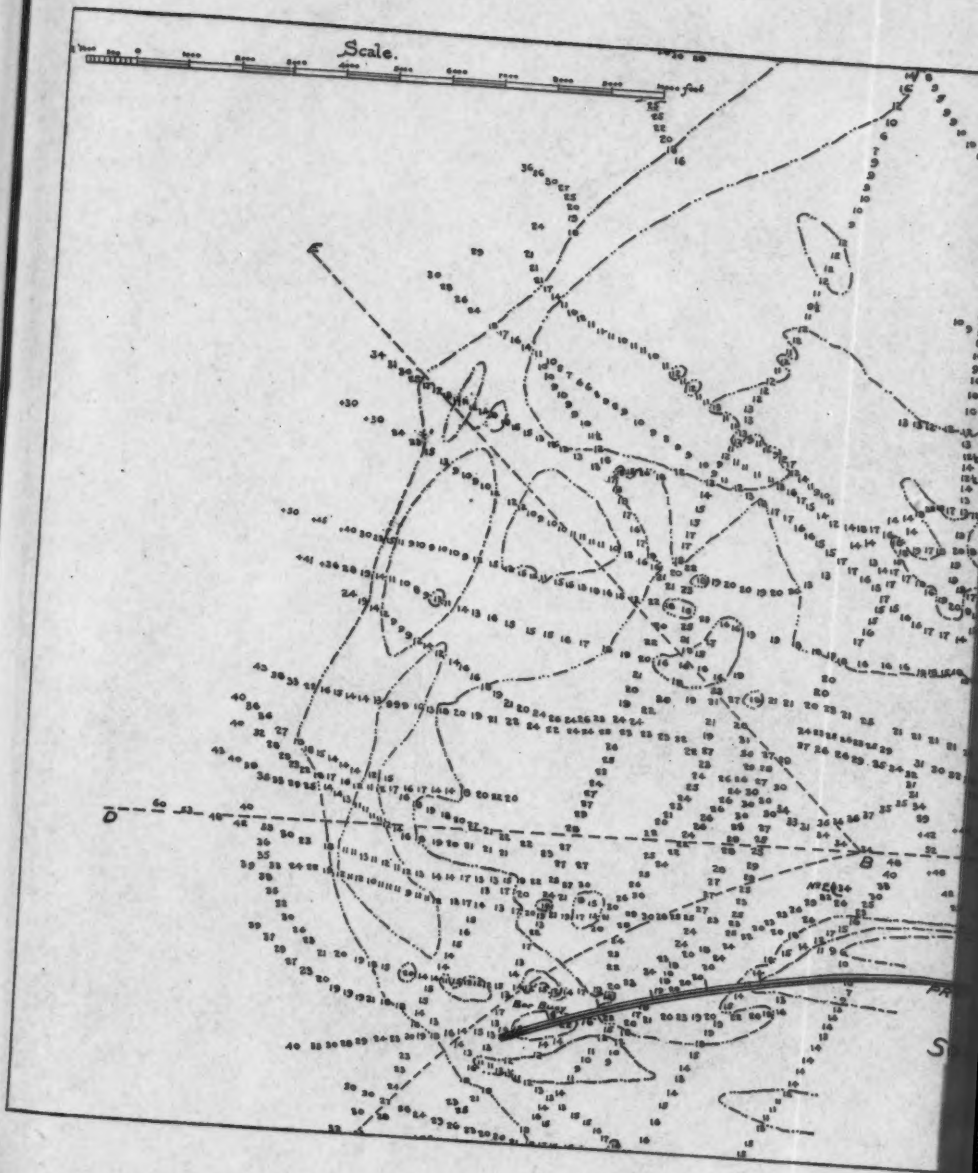
In devising plans for the improvement of the entrances to the tidal harbors of the United States, the general system adopted has been to confine the outflowing and inflowing waters between parallel or converging jetties so located and arranged as to direct the waters upon the bar in a fixed position. Where single jetties have been planned, as at the mouth of the Columbia and San Diego, it has been because the other jetty was replaced by headland or permanent shore. The author's experience in charge of the improvement of a number of harbors on the Pacific Coast has convinced him that there are places where the double jetties are unnecessary and where a single jetty, if properly placed, will, in conjunction with natural tendencies, compel the entrance channel to adopt a fixed and permanent location and practically accomplish all that could be expected of two jetties, and at half, and sometimes less than half, the necessary cost of a pair.

Having to prepare plans for the improvement of the entrance to Grays Harbor in the State of Washington, he became satisfied from a study of the situation, the currents, the tides, the volume of flowing water and the channel movements, that here was a place where a single jetty was applicable. The improvement of the harbor was so planned, and the plan is presented to the Society in this paper, with the facts and reasons which led him to adopt it.

General Description.—It is considered a matter of importance if in certain places it is reasonable to expect to effect a marked and permanent improvement in a harbor entrance by a single jetty. There are places where improvement is greatly needed, where the cost of double jetties would be prohibitory, but which could well stand the expense of a single jetty. It is a satisfaction in making a plan for a single jetty to know that if it be unsuccessful, it will form an essential part of a system of double jetties or other combination of structures necessary to secure the requisite control of the flowing waters.

The entrance to Grays Harbor from the Pacific Ocean lies in latitude 46° 55′ north, being 45 miles north of the mouth of the Columbia River.

The harbor has a length from east to west of 17 miles, and from north to south a maximum breadth of 14 miles. There are a number of rivers tributary to the harbor, the principal being the Chehalis, Satsop, Wynooche, Wishkah, Hoquiam and Humptulips, all of which come from the east and north, and drain one of the richest and most magnificently timbered sections of the State of Washington. There are two main channels crossing the harbor from east to west, of which the north channel is the principal one and the one undergoing improvement at its upper end. A large part of the harbor is occupied by tide flats, bare at low water. The total tidal area of the harbor is 96.8 square miles. At low tide the area covered by water is 30.6 square miles, or less than one-third of the total area. The average range of the tide is 8.4 ft., with a maximum range of 12.9 ft. The low area consists of a number of channels running through and between mud and sand flats. The banks of these channels are quite steep, so that the water does not begin to overflow the flats until it has risen about 2 ft. above mean low water. At about 5.2 ft. above mean low water, the flats are completely covered. Between this stage and mean high water, there is no considerable increase in water area.


Scale.
feet
E
D
B
Bar Buoy

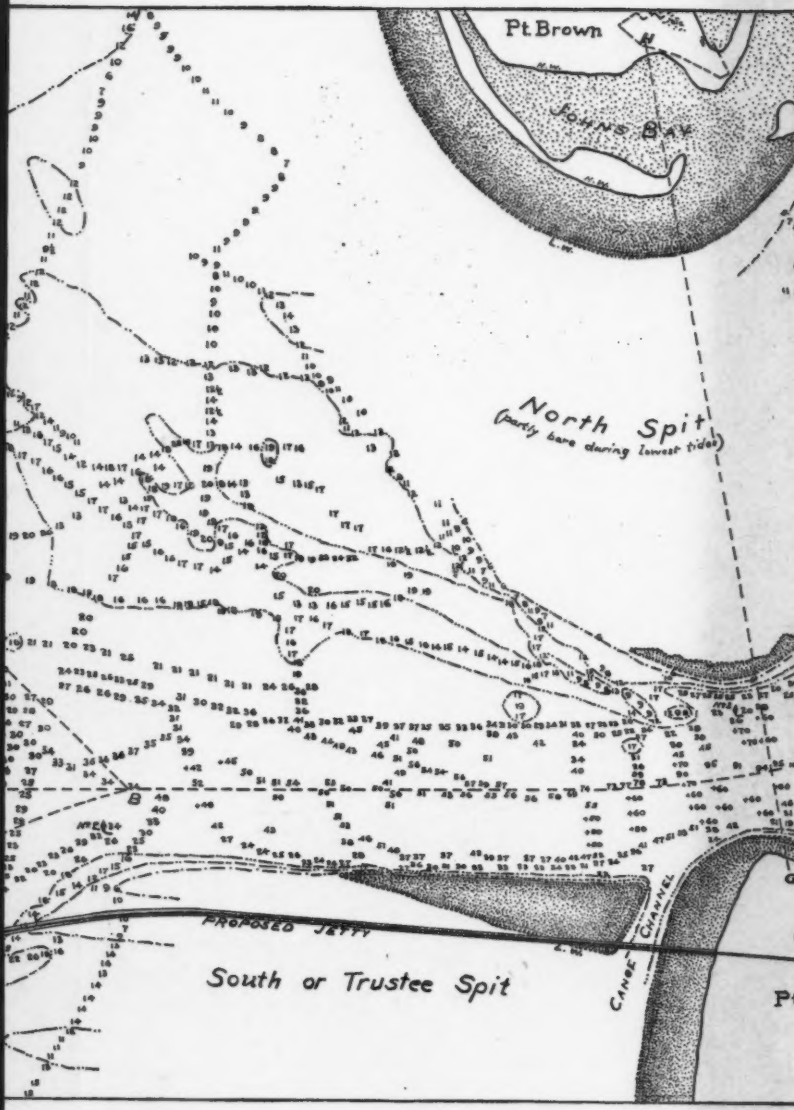
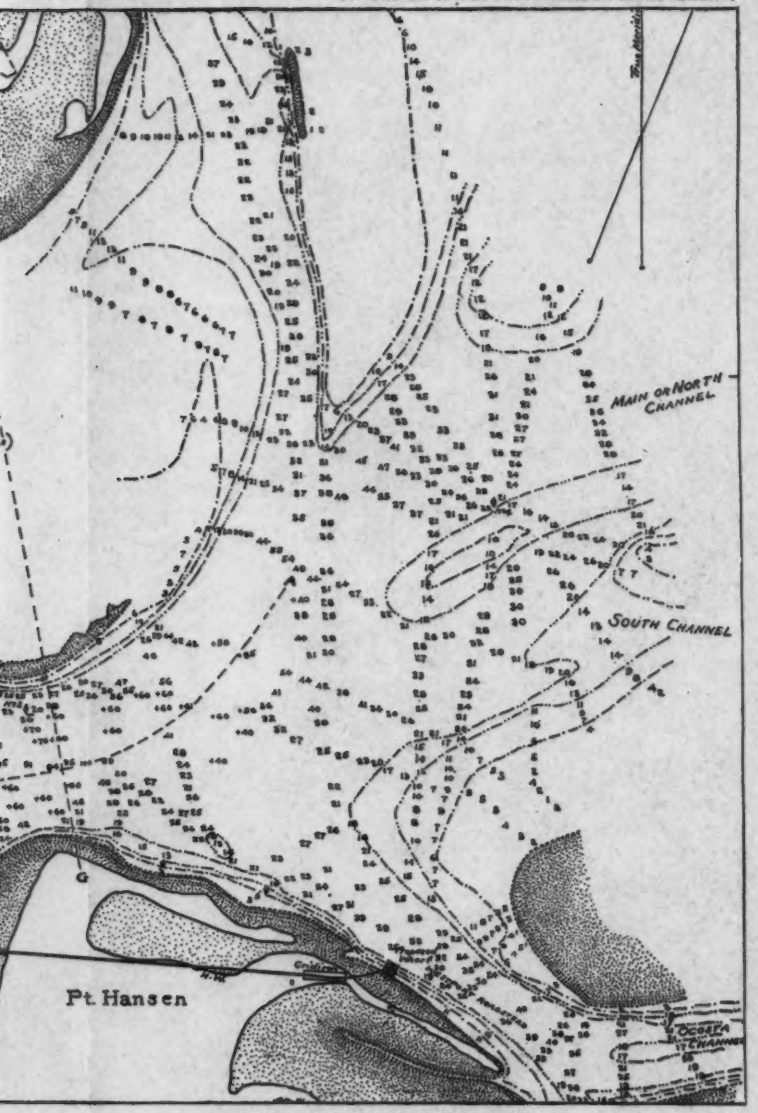
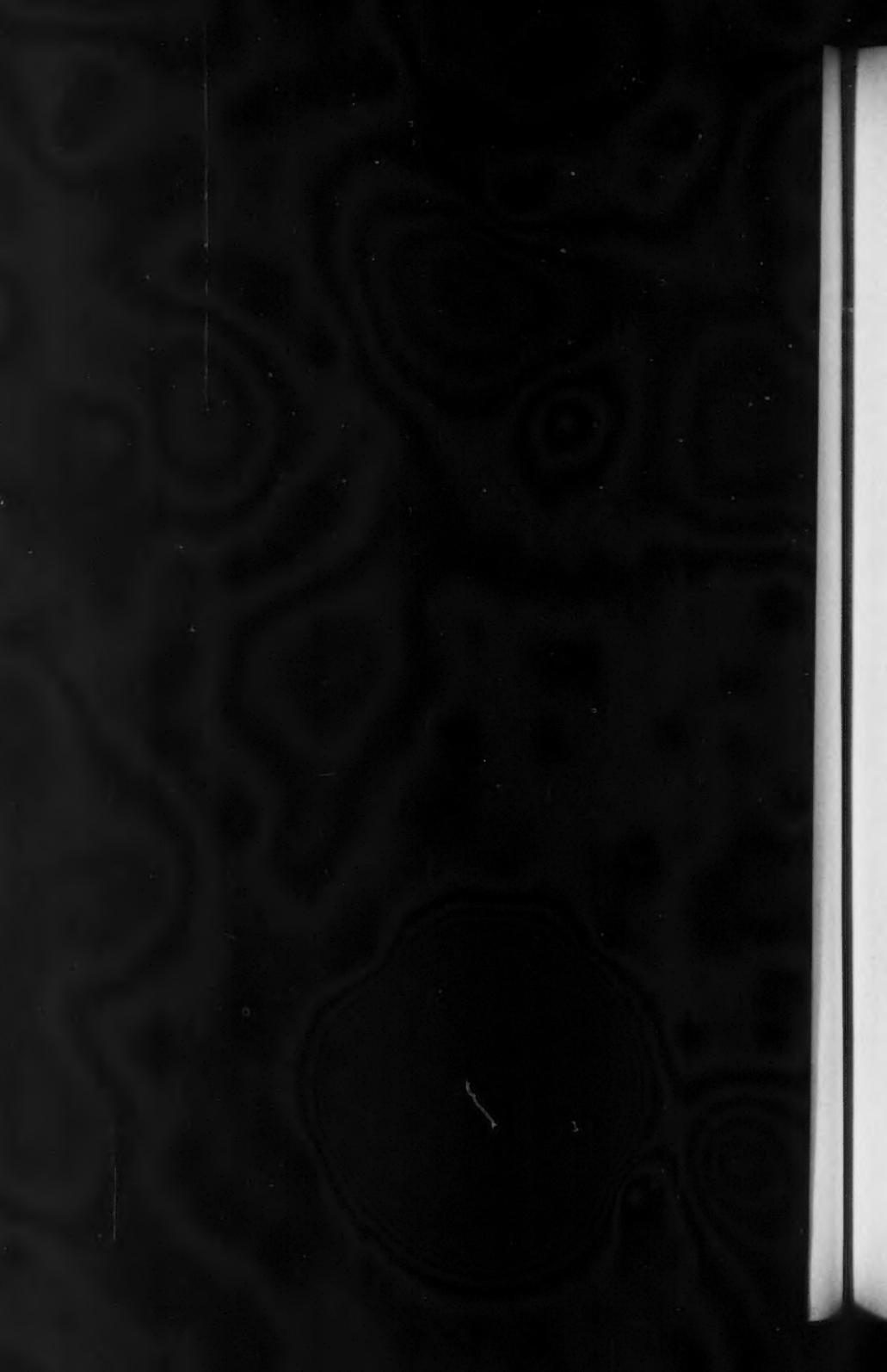

Pt Brown
North Spit
(partly bare during lowest tides)
PROPOSED JETTY
South or Trustee Spit
CANOE CHANNEL

PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXVI, No. 786.
SYMONS ON SINGLE JETTY HARBOR IMPROVEMENT.





From the data available, it is estimated that the volume of water displaced during a mean tide of 8.4 ft. is 16 000 000 000 cu. ft. Assuming the tide to run out for six hours, this gives an outflow of 748 000 cu. ft. per second. The volume of water displaced during a maximum tide amounts to 24 000 000 000 cu. ft., which, assuming the run-out to last six hours, makes a discharge of about 1 100 000 cu. ft. per second.

The harbor throat lies between two low, sandy peninsulas terminating on the north of the entrance at Point Brown, and on the south at Point Hanson. The distance between high-water lines on these two points is 12 500 ft. The survey of Grays Harbor entrance was made in October, 1894. The results of the survey are shown on the accompanying map, Plate IV, upon which is indicated the location of the jetty proposed for the improvement of the harbor entrance. The soundings on the map are in feet, and are referred to the mean of the lower low waters.

The survey shows maximum depths of 100 ft. in the harbor throat. A single broad waterway extends for more than 2 miles from the harbor throat out to sea, with depths gradually diminishing from 100 ft. to 30 ft. Between this deep waterway and the open sea lies the usual bar, convex to the sea, and connected with the spits which jut out from Points Brown and Hanson. The spit from Point Brown is the North Spit, and that from Point Hanson is South or Trustee Spit. Across this bar there is no well-defined, decided, permanent channel. The best water was found at the time of the survey to be in a line southwesterly from Buoy No. 2. This was the channel used by tugs and boats entering the harbor, and was marked by a mid-channel buoy. The survey shows that fully as good a channel existed to the east of this, running more nearly due south. There is also shown nearly as good a channel to the northwest, and also a fairly good one nearly due west.

The governing depth on the bar in the south and southwest channels shown was 13 ft. at mean lower low water. In the northwest channel it was 12 ft.

The general average distance between the inner and outer 18-ft. curves is ½ mile. The region between the two curves was found to be irregular, with lumps and depressions.

On the north of the entrance the extreme limit of Point Brown is a ribbon of sand partially encircling the main higher land, and separated

from it by a tidal lagoon called Johns Bay. The same formation, but less marked, exhibits itself on the south. Maps of the entrance made at different periods show marked changes in the formation about these limiting points.

There seems to be a definite cycle of changes in the end of the north spit abreast of the harbor throat. First, there is an island near the deep water shown on the 1862 map as Eld Island, see Fig. 1. This island gradually works to the north, and finally attaches itself to and encircles Point Brown, as shown on the 1891 map, Fig. 2. This ribbon gradually wears away, as shown on the 1894 map, and, as this proceeds, the island begins to form near the deep channel toward Point Hanson. This island is now in progress of formation, although it was not possible at the time of the recent survey to get any definite soundings on it, to show it in detail. It is, however, indicated in position on the map.

The changes about Point Hanson are less in extent than those about Point Brown. The 1862 map shows an extension of the Point Hanson sands farther to the north than they appear at any subsequent period.

Deep water in the harbor throat lies next to Point Hanson, and occupies about one-third of the width between it and Point Brown. The other two-thirds is occupied by the changeable sandspit above described, which is partly bare at extreme low tide. In the harbor throat the flowing waters have gouged a deep hole. The greatest depth found at the time of the survey was 100 ft., but depths as great as 106 ft. are shown on some of the Coast Survey charts.

A cross-section of the harbor throat is shown in Fig. 3, and upon the same sketch are shown the longitudinal profiles along the entrance channels and the longitudinal profile of the proposed jetty.

The cross-sectional areas of the channel between Points Brown and Hanson are as follows:

	Square feet.
At mean high tide	293 760
At mean tide	245 960
At mean low tide	200 560

This would give, in an ordinary tide, an average velocity through the harbor throat of 3.04 ft. per second, or about 2 miles per hour. In a maximum tide this average velocity would be increased to 4.47 ft.

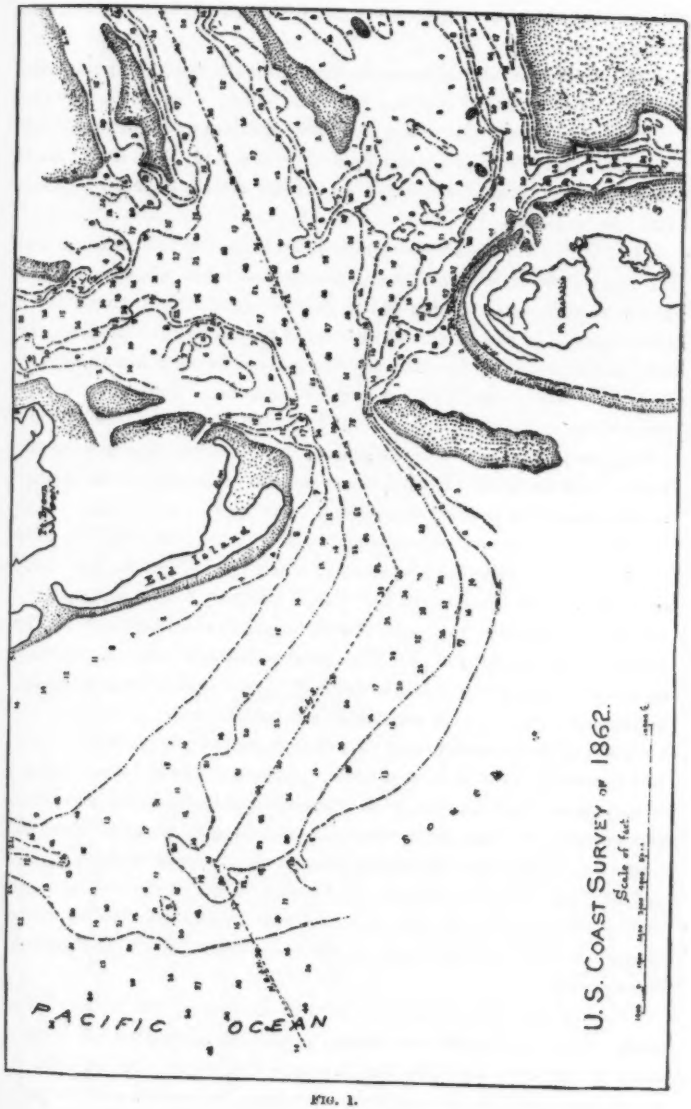


FIG. 1.

per second, or about 3 miles per hour, with extreme velocities of 6 to 7 miles per hour.

Points Brown and Hanson are the terminations of low peninsulas which separate Grays Harbor from the ocean. The Point Brown peninsula is about 7 miles long, and the Point Hanson peninsula about 4 miles long. Both average 1 mile in width and both are covered with a dense jungle of timber to within about 1½ miles of their extreme ends.

In front of the entrance to Grays Harbor the 100-fathom curve lies 32½ statute miles from the general shore line. The 10-fathom curve lies 4½ statute miles in front of the general shore line. This gives a general slope to the ocean bed in front of the harbor of 3.2 fathoms or 19.2 ft. per statute mile. The 10-fathom curve lies but about 3 000 ft. in front of the outer 3-fathom curve of the bar. This gives a very steep slope in front of the bar of 1.4 ft. in 100 ft., a slope which is very conducive to the success of the plan of improvement proposed, as the bar will not be readily formed in advance of its present position after a deep channel is scoured across it.

The Grays Harbor bar projects beyond the general coast line in a crescent shape, as is well shown on Coast Survey charts Nos. 6 100 and 6 400. The material of the bar is fine gray sand. Directly opposite the entrance the outer 3-fathom curve is 4 miles beyond the middle of the harbor throat. The general distance between the inner and outer 3-fathom curves varies greatly, but it may be said to be approximately ½ mile in the vicinity of the bar channel.

The best bar channel varies in depth from 12 to 20 ft., and in direction from nearly south to northwest. As nearly as can be ascertained there is a great cyclic change in the principal bar channel, occurring in about 35 to 40 years, and a lesser one occurring at short and irregular intervals. The greater movement seems to follow or be coexistent with the building up and movement of the sand island off the southern end of Point Brown. When the island is well formed, the best entrance channel is to the northwest; and as the island travels north, the channel travels south.

The entrance channel is at its best when leading out to the southwest. From this position it swings gradually around to the south, until it reaches a direction that is nearly due south. As this movement takes place the channel becomes deeper, but narrow and crooked,

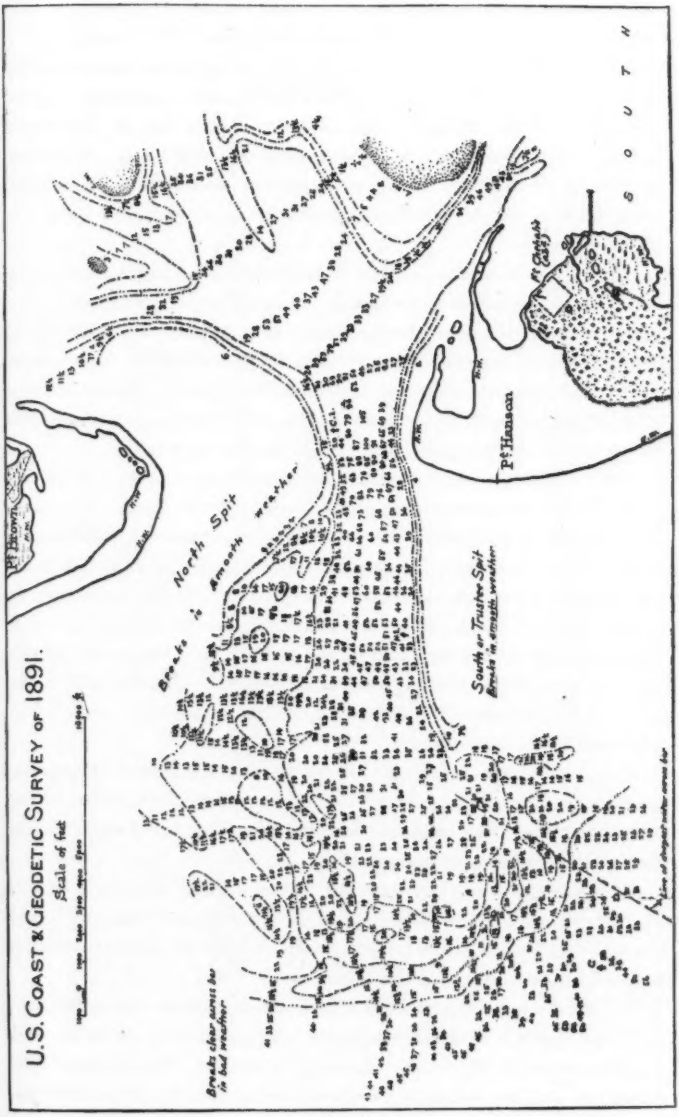

U.S. Coast & Geodetic Survey of 1891.
Scale of feet
Pt Brown
North Spit
Breaks in smooth weather
Pt Hanson
Ft Casey
South or Trustee Spit
Breaks in rough weather
Breaks clear across in bad weather
SOUTH

Fig. 2.

and immediately following this it breaks out to the west and commences to swing around to the southward again. The smaller movement, from west around to south, occurs many times more than the greater from northwest around to south. This constant, gradual movement of the channel from north to south has an important bearing upon the plan of improvement recommended. It is this movement or tendency which it is believed will make a single jetty interposed in its way effective in maintaining a permanent deep bar channel.

During the winter, when the southwest storms prevail, the water is deeper in the entrance bar channel than during the summer. This is attributed to the heavy freshets more than counteracting the effects of the storm to close the bar. The bar channel closes to some extent during the summer, when the milder northwest winds prevail, during which time the sands of the higher spits and beaches are dry, and the ebb and flow of the tide is small, and there are no freshets.

Littoral Current.—In the vicinity of Grays Harbor there is a littoral current, the general resultant of which tends to the north. This general current to the northward is ordinarily considered as the eddy caused by the southward flowing Japanese Gulf Stream. It is noticed all along the coast and has received the name of the Davidson Inshore Eddy Current. While the resultant littoral current is to the north, it ordinarily follows the direction of the prevailing winds in the immediate vicinity of the land, moving to the south in summer and to the north during winter. In intensity it is said to reach as high as 2½ miles per hour either way.

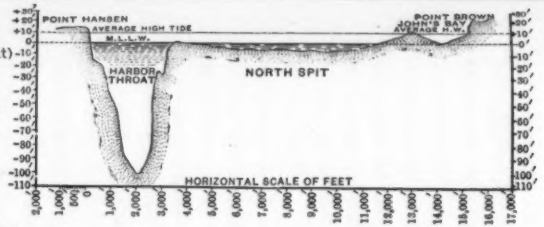
Surveys.—There have been five surveys of the Grays Harbor entrance made, covering a period of 32 years. Three were made by the Coast Survey in 1862, 1883 and 1891, and two by the United States Engineer Department, 1881 and 1894.

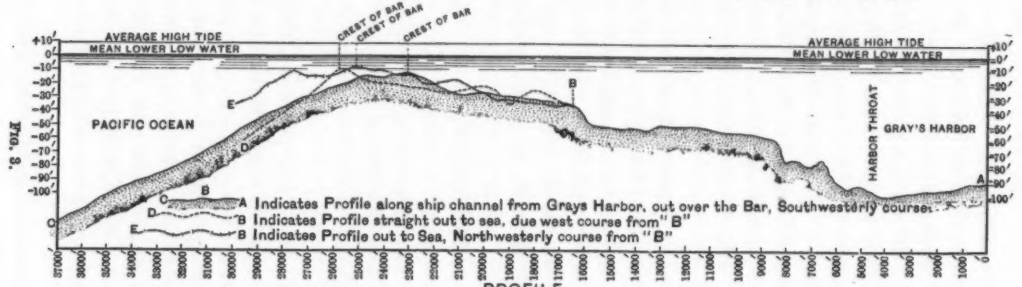
Charts of the surveys of 1862 and 1891 are given in Figs. 1 and 2. The survey of 1894 is shown on a larger scale in Plate IV. The bar and bar channel shown on the charts of 1891 and 1894 are similar, and unlike those shown on the 1862 chart.

In 1862 the bar channel was to the northwest of the harbor throat; in all the others it is to the southwest. The complete charts of 1891 and 1894 show the bar to be in a lumpy condition. The survey of 1862 shows but one channel, that leading to the northwest. It is quite pos-

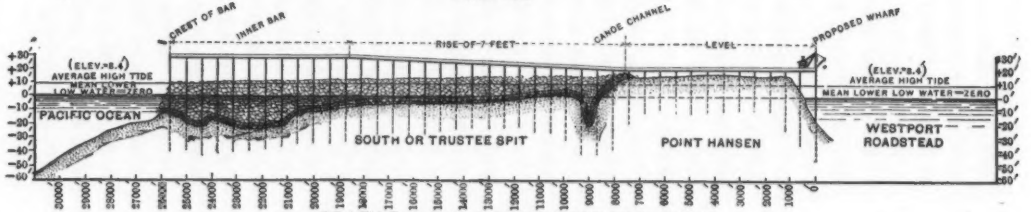
CROSS SECTION AT G H (Harbor throat)

Area of Waterway
At M.L.L.W. = 200,560 Sq. feet
At Mean of H.& L.W. = 245,960 " "
At Mean High Tide = 293,760 " "




AVERAGE HIGH TIDE
MEAN LOWER LOW WATER
CREST OF BAR
CREST OF BAR
CREST OF BAR
AVERAGE HIGH TIDE
MEAN LOWER LOW WATER
PACIFIC OCEAN
HARBOR THROAT
GRAY'S HARBOR
A Indicates Profile along ship channel from Grays Harbor, out over the Bar, Southwesterly course.
B Indicates Profile straight out to sea, due west course from "B"
B Indicates Profile out to Sea, Northwesterly course from "B"

PROFILE



PROFILE ALONG SITE OF PROPOSED JETTY

sible, and in the author's opinion very probable, that a good channel existed also to the southwest, although not shown on the chart. The survey was made in a sailing brig, and the soundings were apparently confined almost entirely to the waterway leading out to the northwest, which was probably the best known channel at the time. No soundings are shown to the south and southwest.

There is another condition bearing upon the question of improvement which is not fully shown on the charts. This is the existence of a channel leading to the south around and close in to Point Hanson. This is indicated on the map of 1862, and slightly on the map of 1881, and was observed, but not surveyed, in 1894. It is marked on the map as Canoe Channel from the fact that it is used by fishermen and others going in and out in small boats, in good weather, when the sea is smooth.

Plan of Improvement.—The plan proposed for the improvement of the entrance to Grays Harbor is based upon the theory of controlling the ebbing and flooding waters to a sufficient extent to concentrate and direct upon the bar in a fixed location a much greater portion of these waters than would naturally go there, thereby scouring a channel across the bar of depth ample for all purposes of navigation and permanent in position.

The large tidal volume and discharge from Grays Harbor furnish the means, if properly directed, to secure a bar channel of satisfactory depth. The ordinary mean tidal discharge is estimated at 748 000 cu. ft. per second. Its tremendous scouring effect is shown at the harbor throat, where, as long as the harbor has been known, depths of 100 ft. have been maintained.

It is recognized that in order to produce a satisfactory channel it is necessary to add to a natural channel but a limited proportion of the ebbing and flooding waters now going elsewhere, provided these waters can be kept flowing there permanently. In other words, it is by no means necessary, as it is not desirable, to direct all the ebbing and flooding waters into a single narrow bar channel. It is also recognized that the safety of any controlling works demands that but a small proportion of the flowing waters be fully controlled by artificial means.

Based upon the ordinarily accepted theories of harbor improvement, as shown by the plans adopted for various places in the United

States, the plan for Grays Harbor would be to confine the outflowing and inflowing waters between two jetties more or less parallel and converging upon the bar at a sufficient distance apart to concentrate and direct the waters in a single bar channel. Recent experiences and consideration of the subject convince the author, however, that at Grays Harbor this ordinary plan can be deviated from, and that one jetty, if properly located, will accomplish results fully as good as two, at a vastly less cost, and without any undue or destructive strain upon the structure from the developed currents.

At Coos Bay, Ore., the one jetty that has been built has caused a bar channel to be developed and maintained fully equal to that which it was hoped to accomplish with two jetties. There the jetty has been interposed against the slow, constant movement of the bar channel to the northward. The plan proposed for Grays Harbor is based largely upon the results obtained and studies made at Coos Bay. At the mouth of the Columbia the single jetty has been eminently successful. Here there is a rocky headland on the north, and the situation is apparently quite different. In reality, however, it is much more similar than it appears at first sight, for the limiting of the waters to the north of the bar channel is due, not to the Cape Disappointment headland, but to Peacock Spit and its tailing sands. There are many points of resemblance in the Grays Harbor problem to that at the Columbia River.

The plan proposed for the improvement of Grays Harbor entrance consists of a single high-tide, rubblestone jetty, founded on Point Hanson, and directed out to sea in a direction nearly due west.

The receiving wharf is located on the south channel inside the harbor sufficiently far to enable stone scows, etc., to be unloaded in safety. The jetty tramway approach thence extends nearly due west 7 300 ft. across the head of Point Hanson. The jetty commencing at the high-tide line also extends nearly due west 10 900 ft. along the South or Trustee Spit at a distance of about 1 000 ft. from its outer steep slope, cutting off the inner or Canoe Channel. Leaving Trustee Spit, it curves to the southwest for 7 300 ft., reaching the crest of the bar at about the present location of the mid-channel bar buoy. Here it stops.

With this location, the water flowing to the southward through the inside coast channel over Trustee Spit, and beyond this to the end of

the jetty, would be stopped from flowing in its present direction, and compelled to go in and out to the north of the jetty. It is believed that these deflected waters, added to the natural waters of the desired channel location, will give an improved bar channel, sufficient for all purposes of navigation.

With the jetty in this location, the slow cyclic movement of the bar channel would be stopped when the latter reaches its best and most satisfactory position, and it is believed that the jetty would maintain it in this position. The jetty would prevent the channel from moving toward the south, and there would be no occasion for it to break out to the west or northwest.

It is this interposition against the gradual movement of the channel that has made the Coos Bay and Columbia River jetties so successful. The same conditions which at Coos Bay have rendered the north jetty effective in maintaining a deep and permanent channel over the bar exist at Grays Harbor, but are reversed. At Coos Bay the bar channel habitually broke out to the west and gradually worked around to the north, getting finally into an awkward trough channel nearly parallel with the coast. The jetty as built is interposed in the way of this gradual channel movement to the northward, and it is to this fact that its good results in giving a permanent location to the bar channel are attributed.

At Grays Harbor the bar channel habitually breaks out to the west and gradually works around to the south, getting finally into an awkward trough channel nearly parallel with the coast. The proposed jetty is located to interpose itself in the way of this gradual channel movement to the southward with the hope and belief that the same resultant action which has been found at Coos Bay will be found at Grays Harbor, with the outcome of giving a deep, permanent, well-directed bar channel.

The situation at Grays Harbor in regard to exposure, latitude, bar changes, and volume of tide water is much more analogous to that at the mouth of the Columbia River than it is to that at Coos Bay. It is in fact very similar to the Columbia. At the Columbia a single south jetty has been projected and constructed, and is eminently successful in giving a deep channel in a permanent location, and this notwithstanding the fact that the entrance between the end of the jetty and Cape Disappointment is over 3 miles in width.

The exposed end of the jetty proposed for Grays Harbor would be nearly head on to the worst storms, those from the southwest, an important point in maintaining its stability. The slightly curved direction given to the jetty trace, convex to the channel, will give the channel whatever advantage there is due to the tendency of tidal flows to follow a convex curve. The channel will also have the direction and location most convenient and desirable for the commerce centering in the harbor.

It was suggested by one in authority that the system of double jetties should be adhered to, the jetties being built about 6 000 ft. apart, protected by groins 500 ft. or more in length, leaving a clear waterway about 4 500 ft. wide. This suggestion was carefully considered, but for the reasons here given was not adopted.

Nowhere on the Pacific Coast, nor on the Atlantic Coast, nor, so far as the author is aware, in the world, has the attempt been made to control between parallel jetties a tidal flow of anywhere near the magnitude of that at Grays Harbor, and the author would view with great apprehension the attempt to build the jetties to so control the tidal flow. With an average tidal flow and the rivers tributary to the bay in their ordinary condition there would be, in a channel 4 500 ft. wide and an average of 30 ft. deep at low tide, a mean tidal velocity of 4.9 ft. per second, or 3.3 miles per hour. In this case the maximum velocity would be about 6 miles per hour. With a maximum tidal run-out in such a channel there would be a mean tidal velocity of 7.2 ft. per second, or 4.9 miles per hour, and a maximum velocity of about 9 miles per hour. This is without taking into consideration the rivers tributary to the bay, which would add considerably to the volume and velocity of the current if they were in a freshet stage.

Such velocities as these are, in the author's opinion, incompatible with safety when they result from the artificial contraction of a waterway by comparatively frail structures built upon shifting sands and exposed to the wave action on a very stormy coast. It must be admitted that such a great volume of water as that of Grays Harbor, moving with the stated velocities and aided by wind and waves, is a tremendous power and liable to play havoc with any works exposed to its full force. This is to be avoided, if possible, and it is with this end in view that it is proposed to control as small a portion of the flowing waters as possible consistent with attaining the desired end.

At the harbor throat or gorge the cross-sectional area of the waterway at mid-tide is 245 960 ft., and here depths of 100 ft. are regularly maintained. With a width of 4 500 ft., this same cross-sectional area could only be obtained by an average depth throughout of 54 ft. It could, therefore, naturally be expected that between the jetties spaced as indicated, there would be depths exceeding 60 ft., which depth confined in the immediate vicinity of a rubble stone jetty founded on sand would be very threatening, even though the jetty were guarded by long and expensive groins.

At only two points on the Pacific Coast have systems of parallel jetties controlling the tidal expense in one concentrated stream been practically completed—at Wilmington and at Yaquina. At Wilmington the tidal flow is only one-one hundred and twentieth of that at Grays Harbor, and at Yaquina only one-twentieth of that at Grays Harbor.

The author's experience is such as to convince him that it would probably be found impossible to build a second jetty at Grays Harbor within 6 000 ft. of a first one by the ordinary method which has been and is being used on this coast. As this second jetty would be built out, the currents would scour a channel in front of it until the depths would become too great for the construction of a pile and timber tramway. As the seas in the locality are too rough to permit of the construction of the jetty from floating plant, there would be the necessity of devising new methods of construction, which would surely be far more expensive than those ordinarily used.

As indicative of the unusual magnitude of the work of improving Grays Harbor by a system of parallel jetties in the manner suggested, a table is given on page 123 showing the mean range of the tide, the tidal area, the mean tidal discharge, and distance apart of the proposed jetties for Grays Harbor and other harbors of the United States, where jetties have been or are being constructed, concerning which the author has been able to get information.

On the direct line from Point Brown to Point Hanson, the line upon which the greatest depth is found, the midtide section has an area of 246 000 sq. ft. The maximum depth on this line is about 100 ft., a depth entirely inadmissible in the vicinity of jetties unless the jetties be protected by very long and costly groins.

If a system of double jetties were adopted it would be necessary to provide a minimum waterway between them fully equal to 246 000

sq. ft. Assuming an average midtide depth of 20 ft., this would require that the jetties should be spaced fully 2 miles apart, if built to high tide.

If this width were narrowed there would be a tendency to dangerous undermining of the jetties, which would increase as the width diminished. Within this necessary width of 2 miles there would undoubtedly develop one or more channels of much greater depth than 20 ft. at midtide. Such a channel might occupy any position between the jetties, and, on leaving their concentrating influence, would have

Locality.	Mean range of tide.	Tidal area.	Mean tidal discharge per second.	Distance between jetties at sea ends.	Remarks.
PACIFIC:	Feet.	Square miles.	Cubic feet.	Feet.	
Columbia River.....	6.2	*140	1 000 000	18 900	High tide single jetty. Width between end of jetty and Cape Disappointment.
Grays Harbor.....	8.4	96.8	748 000	6 000	Reduced to about 4 500 ft. by groins. Suggested width.
San Diego.....	3.7	25.5	97 000	4 000	High tide single jetty. Approximate width between end of jetty and Point Loma.
Humboldt Bay.....	5.5	24	100 000	2 100	High-tide jetties.
Coos Bay.....	5.5	24	100 000	1 500	" "
Yaquina Bay.....	7.0	5	38 000	900	" "
Siuslaw River.....	5.2	5.4	30 000	600	" "
Coquille River.....	4.1	3.6	15 000	600	" "
Wilmington Harbor..	4.0	2.25	6 000	700	" "
ATLANTIC:					
Galveston Harbor.....	1.1	450	250 000	7 000	High-tide jetties.
Charleston Harbor...	5.1	15	170 000	2 900	Low-tide jetties.
Cumberland Sound...	6.0	27	202 000	3 900	" "
Winyaw Bay.....	3.5	12	120 000	4 000	High-tide jetties.
St John's River.....	4.3	(?)	76 500	1 600	
Sabine Pass	1.4	120	50 000	1 700	High-tide jetties.
Newburyport.....	7.5	(?)	(?)	1 000	" "

* To Cathalmet.

almost as great latitude in choosing its direction as would be the case of a channel with but a single jetty as directrix. It is therefore believed that it is unnecessary to provide a north jetty or make provision or estimate for any other construction than the south jetty.

It is proposed that the jetty shall extend to the ordinary crest of the bar in its present location. This would give a total length for the structure of 25 500 ft. from the receiving wharf to the end. The jetty proposed is a rubble mound founded on a brush mattress, the

whole built from a pile and timber tramway extending from the shore, the enrockment to be brought well above high tide.

The estimated cost of the work is as follows:

Plant including wharf, engines, derrick, locomotives, cars, machine shop tools, building, stone barges, lumber and brush barges, etc.	$153 955
Tramway, 25 500 ft. long	102 590
Mattress foundation, made of small spruce trees laid diagonally	61 900
Enrockment. Rock brought from the Columbia River, 441 100 tons at $1.07	471 977
Groins. Five, each 200 ft. long	40 940
Shore protection	15 000
Engineering, superintendence, office expenses, etc., 5 per cent	42 318
	$888 680
Contingencies, accidents, delays, repairs, care of property, etc., about 12½ per cent	111 320
	$1 000 000

The cost of the double jetty system applied to Grays Harbor, as suggested, would be about $2 500 000. Owing to difficulties that might be encountered in building the second jetty, and the possible necessity of greatly strengthening both jetties, it might be even more than this.

It is not to be denied or contended that when the single jetty is completed it may be found essential to its success to put in some shore protection or other minor works, to develop and render stable the best condition of the North Spit, but the expense of such works would be slight.

DISCUSSION.

G. F. Allardt, Esq.—In the year 1890 the speaker was called upon by the Hawaiian government to devise a plan for deepening the bar off Honolulu Harbor. The bar is about 1½ miles from shore, with a depth of 20 ft. on its crest at low tide, and consists of a deposit of coral sand, intermixed with scattering masses of coral more or less compacted or cemented. Across this bar it was proposed to excavate a straight channel 200 ft. in width to a depth of 30 ft. at low tide. The distance from the 30-ft. depth on the harbor side to the 30-ft. depth on the ocean side was 1 200 ft., and the necessary excavation amounted to about 70 000 cu. yds. In his report the speaker recommended that the excavation be made by means of a hydraulic dredge, and that the excavated material be utilized in reclaiming some shallow mud flats belonging to the government, and distant about three-fourths of a mile from the bar. Owing to the scarcity of competing contractors on the islands, it was suggested that the government acquire its own dredging plant, that the actual work of dredging be let out by the cubic yard, and that the plant be subsequently used by the government in deepening and extending the inner harbor. The recommendations were substantially adopted, and the legislature made an appropriation of $200 000 for the improvement. Mr. Allardt.

A contract was entered into for a first-class hydraulic dredge with all the necessary pipes, floats, etc., for handling and transporting the material. All machinery and iron work were made in San Francisco and then shipped to Honolulu, where they were fitted to the wooden hull constructed there, it having been considered hazardous to tow the completed machine across the ocean. The cost to the government of the dredging plant complete was $77 300.

Considerable delay in beginning the work was occasioned by rough weather, and when the work was commenced the contractors found it necessary, on account of the wave motion of the sea, to abandon the use of the revolving cutter and the spud mooring. A cast-iron mouth-piece was therefore substituted for the cutter, and connected with the suction pipe by a flexible pipe, and with this contrivance it was found that the coral sand could be drawn in to the full capacity of the pipe with no other means of loosening it than that furnished by the current of water sucked in by the pump. The spud mooring, which is used to such advantage in smooth water, was replaced by anchor moorings, with which it was difficult to keep the dredge exactly in the desired position, and the result was that the bottom of the cut presented a succession of hummocks and pits. The contractors, however, faithfully expended much time and money in removing and leveling off

Mr. Allardt.

the hummocks, so that upon the acceptance of the work the depth of water at no point was less than that required by the contract. On June 1st, 1893, the excavation was completed and the bar opened to commerce. In the language of the Minister of the Interior, "it was an improvement that opened our inner harbor and wharf facilities to steamers of the largest class touching here from China, Japan, Australia, San Francisco, and British Columbia."

No perceptible filling has since taken place in the dredged channel, the scouring action of the ebb tide, though very feeble at Honolulu, being evidently sufficient to prevent any considerable deposits. Since the bar has been completed, the government has utilized the dredging plant with excellent results in deepening and extending the inner harbor.

In view of the experience above set forth, the question may well arise whether the method adopted at Honolulu may not be applied advantageously to removing the bar at Grays Harbor. The relative situation in both places is much the same. At Honolulu there is a bar of coral sand, at Grays Harbor a bar of "fine gray sand," both bars being located in the open sea far from shore, and both exposed to the full sweep of the Pacific Ocean.

From careful measurements on the author's chart it is possible to make a fairly close estimate of the amount of excavation required to obtain a given width and depth of channel. Let it be assumed, for example, that a depth of 24 ft. at low tide is desired. This would give a depth of 32.4 ft. at average high tide and a depth of 36.9 ft. at the maximum high tide, far better water than is found in New York Harbor. Assume further, a bottom width of 200 ft., with side slopes of two horizontal to one vertical, then the total excavation would amount to 186 000 cu. yds. The cost of hydraulic dredging on the Pacific coast in comparatively still water ranges from 12 to 16 cents per cubic yard. On the Honolulu bar the cost ran up to 70 cents, but this price included the work of making the necessary walls and levees to retain the material on the land that was reclaimed. At Grays Harbor, however, there are no reclaimable areas within a practicable distance; probably the cheapest dumping ground would be the bottom of the sea outside of the bar, say, at a depth of 50 ft. This would require about 4 000 ft. of piping, which should be submerged in order to be beyond the action of the waves. Under these conditions, and considering the lively competition in dredging work on this coast, the cost per cubic yard should not exceed 50 cents; but even at the high price of 70 cents per cubic yard the entire cost of deepening the bar and making Grays Harbor accessible to the largest ships would amount only to $130 200.

The author estimates the cost of a single jetty at $1 000 000, and while he believes that one jetty will answer the purpose, he admits

that a double jetty may, after all, be required to produce the desired result. He puts the cost of a double jetty at $2 500 000, or nearly twenty times the cost of excavating a channel by the dredging process. It may be contended that a dredged channel would be liable to silt up in the course of time, but this is an extremely remote and improbable contingency. A comparison of the charts of 1862 and 1894 (32 years) shows no material change in the depth over the bar, the minimum depth being 9 ft. at low tide on both charts. Grays Harbor bar, like other bars in tidal waters, was formed by the action of opposite forces from within and without, which, in the course of time, finally reached an equilibrium and resulted in the present permanent condition of the bar. If this condition be disturbed by artificial deepening, the same forces would tend to restore that equilibrium; but this action, judging from the immobility of the bottom during the past 32 years, and probably much longer, would undoubtedly be extremely slow, and many years must elapse before any considerable filling would take place. Mr. Allardt.

It seems evident, moreover, that when a channel is once cut through the bar, the main current of the outflowing water will naturally seek the deeper channel, just as the most rapid current in rivers invariably follows the lowest depressions, and instead of silting up the channel, would have a tendency to scour it still deeper. However that may be, the great difference of cost in favor of dredging as compared with the jetty system certainly warrants a more thorough study of the problem before the United States government commences active operations at Grays Harbor.

G. H. Mendell, M. Am. Soc. C. E.—The natural conditions of tidal expense, exposure, prevalence of sand, slope of sea floor and meteorology are much the same at Grays Harbor as at the Columbia River entrance. The successful treatment of the latter leads one to expect favorable results from the application of the same principles to the development of the former. Col. Mendell.

The Columbia River entrance before and after improvement is illustrated in Figs. 4 and 5*. A single wide, deep and commodious channel, a very large accumulation of sand on Clatsop Spit and a a redistribution of sand deposits, interior and exterior, are the main changes to attract attention. There have usually been two or more ship channels over the bar, varying considerably in position and depth. Clatsop Spit has at times, in a state of nature, been bare at low water over a great part of its area and considerable portions have stood several feet above the low-tide plane. Contemporaneously a bar entrance of satisfactory dimensions was developed, succeeded by indifferent channels when the shoals were much lowered or their continuity much broken. Clatsop Spit was for the time a jetty, but as

* Two more charts of the Columbia River entrance were printed in *Transactions*, Vol. xxviii, Plate xx.

Col. Mendell.

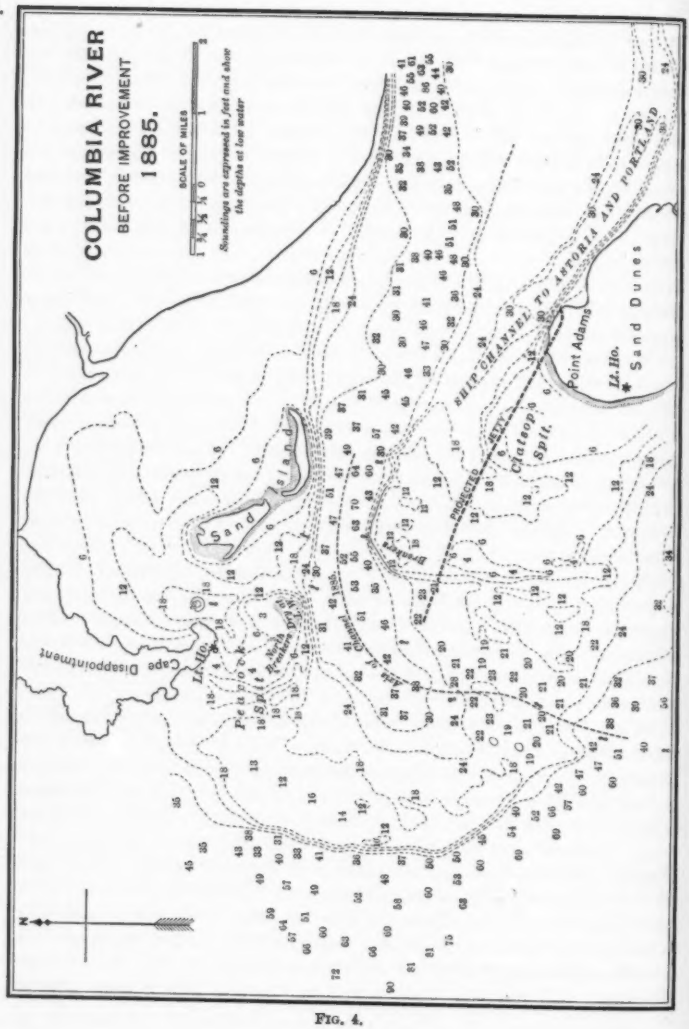


FIG. 4.

Col. Mendell.

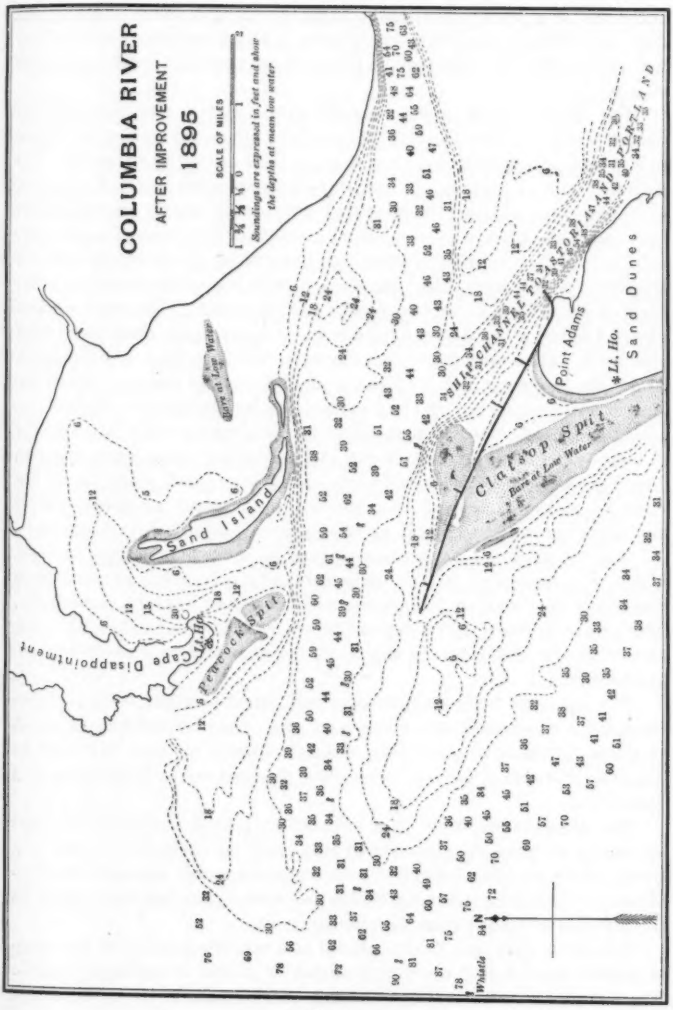


FIG. 5.

Col. Mendell. sand yields to the slightest influence of wave or current, the Spit is variable in plan and elevation, and cannot of itself steadily fulfil the functions of a jetty. The sands on the north side, including Peacock Spit, have always been variable, but the rocky promontory of the Cape has given sufficient constancy to form a good northern bank equivalent to a jetty.

The stone line or jetty extends over Clatsop Spit seaward for nearly 5 miles. The specific purpose of this work is to give permanency to Clatsop Spit, holding it at as high a level as possible. The Spit also gives protection to the jetty on the weather side. But for the sand here accumulated the so-called jetty could hardly be held above low water, for it is necessarily built of country rock, of maxima weights of 7 or 8 tons, affording insufficient resistance to sea waves. At the western end the work has been flattened by waves to about low-water level, although built more than once to high water. The shore end for about 3 miles is held above high-tide level, gradually falling to mid-tide level. Generally described, the work is held as high as practicable under the exposure and with the available sizes of stone. While the line is fairly protected on the weather side by the shoals which it impounds, it needs special protection on the channel side against the ebbing current and against racing and enfilading waves from the sea. Being for the most part founded in shoal water and upon sand, the work is at the mercy of an undermining current or wave. It is therefore necessary to break up racing waves and to divert currents. As these sources of disturbance develop power to injure in deep water, it is necessary to keep deep water at a distance. Protection on the inside is provided by groins, which are also lines of stone work. The proper groin lengths depend upon, and are multiplies by a safe factor of, the difference in depth of the foundations and of the adjacent channel.

The jetty, to fulfil its functions best, must be tight, with no large interstices through which water and sand may circulate. It must therefore be made in great part of small stones, at least sufficient in quantity and varied sizes to reduce the dimensions of interstices to a minimum.

The dynamic principle of a work of this kind is that, to as great an extent as possible, the effluent tide shall be carried as a unit in a deep, direct channel, extended under control as far seaward as practicable. This principle may be applied with equal ease and safety to all volumes of tidal prism, howsoever great.

The stone lines are to be placed at a safe distance from the deep adjacent channel, and are to be guarded by groins of sufficient length. The channel which conveys the tidal efflux ought to be proportioned in width so as to maintain a low-water depth at least twice that expected to result at the bar. The deeper and more concentrated and

more direct is this current, the longer after control is released will its stored energy remain and the better ought to be its expected action upon the bar. According to the view here taken, the spacing or distance between the stone lines plays no necessary part in securing the best results upon the bar. The great requirement is that the lines shall be protected, either by sand deposits or groins or by both. A slight convexity in alignment toward the channel side is also a safeguard against undermining, either by waves or by currents. Col. Mendell.

Whether the bar be due merely or mainly to littoral sand movement, or whether it be due to deposits made by waves, or, as obtains upon the Pacific Coast, to both causes, the best chance of counteracting these hostile influences seems to lie in a concentration of the force which makes for depth. An adequate tidal prism duly controlled for a conserving force, an abundance of sand for protection of the slight construction in country rock, and a fair slope in the sea floor, are main conditions which may be said to ensure success upon the Pacific Coast.

A single jetty cannot, in the general case, be said to fulfil the first condition. At most it does a partial service. It is good as far as it goes. It limits the azimuth of variation in channel alignment, but does not determine a single channel.

The conditions of the Pacific Coast are not favorable for success by dredging alone. The constant heave of the sea, the frequency of gales, the distance of the bar from shore, the continuous shifting of sand requiring steady excavation and the impossibility of ensuring it, seem to rule out dredging as a sole means of bar improvement, unless in exceptional instances.

CORRESPONDENCE.

Capt. Abbot.

F. V. ABBOT, M. Am. Soc. C. E.—The valuable paper on the Grays Harbor project brings out very forcibly what the writer believes to be the *sine qua non* of any successful improvement of a harbor entrance obstructed by a shifting sand bar, viz., interfere with existing conditions just enough to produce the desired local effect, but not enough to produce such extensive changes as to introduce new and unknown factors into the indeterminate equations between the forces tending to close up, and those tending to deepen and enlarge, the entrance. The bar itself is the resultant effect of all the forces acting on the movable sands of which it is composed. An attempt to oppose violently any of these forces will develop in the most convincing manner the vast potential stored in moving water. The attempt should be to concentrate and assist those forces which are favorable, and at the same time to oppose slightly those which tend to close the entrance.

Under the latter head the author does not mention one which has to receive most careful study on the South Atlantic Coast. This is a general drift of material along the coast. At a number of entrances on this coast, the drift is so enormous that a single jetty such as he proposes would be foredoomed to failure. On the Pacific Coast the material composing the shores appears to shift locally sometimes one way and sometimes in the opposite direction. Under such conditions there appears to be good reason to hope for a successful single jetty project.

The principal opposing forces are the flood tide and waves; the aiding force is the ebb tide, including the fresh water derived from the rivers discharging into the bay. The great difficulty is to modify the balance between these forces by a single jetty so that the ebb may overcome the combined energy of the flood and wave action to such limited extent as to produce the desired local deepening without altering the general regimen of the entrance.

The position and form assigned the south jetty being unquestionably the result of prolonged expert study of many facts and much data that could not be compressed into the narrow limits of a Society paper, it would be simply arrogant assumption to discuss it in detail, but it may be well to consider some points about it in a general way. The further the trace or ground plan is moved to the north, the greater the effect produced on the bar will be, and also the greater will be the danger of scour too near the structure. The form of jetty convex to the ebb is the exact reverse of that successfully used at Swinemunde. It is well adapted to securing immunity from scour, but to

determine the degree of curvature demands engineering ability of the highest order. Too great a radius of curvature fails to protect against the formation of a channel too close to the structure; too small a radius enfeebles the effect at the very point, at the bar itself, where the maximum effect is needed. The southward shifting of the natural channel is the measure of the resultant force to be opposed, and the jetty must be strong enough in cross-section and trace to withstand this force successfully. The less the radius of curvature, the less the cross-section required to meet this attack, but the action of heavy waves may be increased if the curvature is too sharp. Capt. Abbot.

The further south the whole jetty is placed, the less is the danger of undermining, but also the effect is less on the bar. The cost is greatly affected by the depth in which the jetty is built, so that the configuration of the present bottom must be considered in addition to all the other factors that enter into the study. In a case of this kind mathematics must, as in many other cases of engineering study, be well subordinated to hard, practical common sense.

LEWIS M. HAUPT, M. Am. Soc. C. E.—The improvement of each harbor entrance is an independent problem, and the success or failure of the work must depend upon local agencies, yet there are certain general, fundamental conditions which must be complied with before success can be attained. The chief of these is the resultant direction of the littoral drift. On this point the paper seems to be somewhat ambiguous. It reads: Mr. Haupt.

"As the island travels north, the channel travels south. The entrance channel is at its best when leading out to the southwest. From this position it swings gradually around to the south, until it reaches a direction that is nearly due south. As this movement takes place the channel becomes deeper, but narrow and crooked, and immediately following this it breaks out to the west and commences to swing around to the southward again. * * * It is this movement or tendency which it is believed will make a single jetty interposed in its way effective in maintaining a permanent deep bar channel."

If the channel movements are as stated in this quotation, then the prevailing littoral drift must be in the same direction, and the proposed jetty will be on the wrong side to interpose an effective resistance to the forces forming the bar. Experience in jetty construction on the Gulf Coast leaves no doubt as to the injury and expense resulting from the improper conduct of such work. In one case, a bar was pushed out to sea at least 2 miles, adding 4 miles to the length of jetties to be built, merely because the littoral drift was not arrested on the near side of the channel. In short, the wrong jetty was built first.

At the mouth of the Columbia River the original design contemplated two jetties, as did the plan for Coos Bay, but the fortunate construction of the first jetty on the proper side of the entrance intercepted the littoral drift, conserved the energy of the ebb over the bar, and produced the required depth, rendering a second jetty unneces-

Mr. Haupt. sary. Concerning the littoral current at Grays Harbor the author states: "There is a littoral current, the general resultant of which tends to the north. * * * Its intensity is as high as 2½ miles per hour either way," and its direction in the immediate vicinity of the land veers with the wind. While the draught current should be northerly from Cape Mendocino along this part of the coast, the southerly drift of bars enclosing the channels is a warning to look for some local eddy disturbance at this point, else the jetty will fail of its purpose and the experience on the Gulf will be repeated.

The writer's experience leads him to the conclusion that even the single jetty may be made much more effective by building it detached and concave to the ebb stream, so as to develop the centrifugal force of the currents locally over the crest of the bar. The laying of the foundations of the jetty at Aransas Pass, where there is a mean tide of only 14 ins., and the placing of a small portion of the superstructure produced phenomenal results. Here the usual order of procedure was reversed, and the work was commenced, as directed, on the outer slope of the bar to prevent any seaward movement and induce an immediate scour. The anticipated effects were more than realized. The report of the resident engineer, William Dunbar Jenkins, M. Am. Soc. C. E., showed that within a few months after the first mattress was laid, the outer and inner slopes were reduced and the crest lowered more than 3 ft., while the distance between the outer and inner contours was reduced nearly one-half.

What is needed in such improvements is a local treatment by a reaction breakwater extending across the crest of the bar on the side of the channel whence comes the littoral drift, so as to intercept it. This breakwater should have sufficient development shoreward to control enough of the ebb energy to cut a channel of the requisite depth without impeding the entrance of the tidal volume. Twin jetties, sufficiently close to act together, and running out from a harbor entrance where the tidal movement is as great as at Grays Harbor, would not only injure the inner channels, but would soon be destroyed unless a large sum was spent annually for their maintenance.

Although the jetty at the mouth of the Columbia River has accomplished more than was anticipated, it by no means follows that a similar jetty, similarly placed at Grays Harbor, will produce the same effect, because of the different conditions. Sufficient data are not given in the paper to permit of a definite solution of the problem, yet the writer believes that the author will be able, with the material accessible to him, to secure much better results at less than half the cost by employing a single jetty, placed correctly, rather than twin jetties. The writer's purpose in this communication is to call attention to the danger and disappointment which may result from placing the structure on the wrong side of the proposed channel.

Maj. Symons.

T. W. Symons, M. Am. Soc. C. E.—Naturally the first question that would arise in the mind of an engineer called upon to devise a plan for deepening the entrance to a harbor would be: "Can it be done by dredging?" Mr. Allardt's experience causes him to ask this question. To the engineers who have been engaged on the North Pacific Coast the method of improving a harbor entrance opening directly upon the ocean by dredging through the bar is now never seriously considered. No time is wasted upon it, as it early becomes evident to every student and observer that such a method is entirely impracticable. The sands move so freely and in such enormous volumes, under the influence of the frequent and terrific storms to which the region is subject, that no reliance can be placed upon any channel which is unable, with the existing forces, to maintain itself against all existing forces, and if necessary to renew itself. If it is conceived that at Grays Harbor a channel be dredged such as Mr. Allardt proposes, it is practically certain that the first severe storm would wipe it out of existence. Good natural channels across the bar have existed at many times, but they change in location and entirely disappear with remarkable rapidity. If these natural channels are not maintained, how could permanency be expected in an artificial channel 200 ft. or 300 ft. wide? Mr. Allardt's proposed method of cutting a channel is impracticable. No dredge with anchor moorings could live and work upon Grays Harbor bar, even in the mildest weather, for more than a few hours at a time, and for a very few days in a year.

The only possible way of dredging on the bar would be by the use of self-contained, sea-going, hydraulic dredges like those used on the New York bar, one of which is in use on the Columbia River for removing bars from the inner river. Even this could work only with great difficulty and risk, and for but a small part of the time.

If Mr. Allardt were familiar with local conditions, he would come to the conclusion of all other local engineers, which, as expressed by Col. Mendell, is that "the conditions of the Pacific Coast are not favorable for success by dredging alone," and this is particularly true along the northern part of the Pacific Coast of this country, where storms of great violence are of frequent occurrence and where the sea is almost always rough, the sand movements great, and the channels change in location with great rapidity and over wide areas.

The testimony of engineers is conclusive as to the existence of a well-defined littoral sand drift along the Atlantic and Gulf Coasts, which is permanent in direction, and which, of course, is a factor of prime importance in any scheme of improvement. On the Northwest Pacific Coast there is no such defined drift. The great sand movements are not due to a permanent littoral drift or current, as this is generally understood, but are due to local causes and to ever-changing winds and currents, which effect a distribution and redis-

Maj. Symons.

tribution of the sands existent about the harbor entrance and brought down by the tributary rivers.

The littoral current in front of Grays Harbor, as stated in the paper, runs both ways with varying intensity, and any work planned with the sole object in view of arresting littoral drift would be out of place there.

Prof. Haupt is in error in stating that the original plan for the improvement of the Columbia River contemplated two jetties. It only contemplated one, and estimates were made for but one, for the jetty which has been built. At Coos Bay two jetties were planned and estimated for. The first one built has been successful in developing and maintaining a bar channel fully equal to that which was hoped for from the two jetties. Even in the case of the work at Coos Bay the selection of the north jetty, as the first to be built, was not the mere fortuitous circumstance which Mr. Haupt infers it to have been. It was decided upon, after a careful consideration of all the prevailing physical phenomena, as the one which would do the most good, especially after it had been pushed out far enough to interpose an effective barrier to the constant northerly trend or movement of the entrance channel across the bar. Prof. Haupt is again in error in saying that "the jetty at the mouth of the Columbia River has accomplished more than was anticipated." The engineers who designed this work fully expected it to accomplish all that it has accomplished.

The action and function of these jetties is more complex than simply to arrest the littoral drift. This, in fact, is but a secondary function of either of the jetties; the primary function being to act as a directrix to the ebbing waters. Together with the natural tendencies of the channel to move in a certain direction, each develops a channel in a particular location and keeps it there.

In planning jetties for the improvement of a harbor on the Northwest Pacific Coast, and particularly in planning a single jetty, the trend and changes in the ebbing and flowing currents are factors of far more importance than the littoral drift, which Prof. Haupt seems to consider as of prime and sole importance.

The method of construction adopted at Aransas Pass would be inapplicable and impossible at Grays Harbor. The water is too rough to permit the construction of jetties from floating plant, as done along the Atlantic and Gulf coasts. One of the reasons for placing the jetty convex to the channel was to guard it against the very centrifugal forces of the currents which Prof. Haupt would develop. It is essential to the safety of a jetty built as this is planned, in a comparatively frail manner on a shifting, sandy foundation, to keep it as far away from the developed channel as possible. As the author endeavored to make clear, the volume of tidal flow at Grays Harbor is so great that but a small portion need be controlled in order to secure a channel

over the bar of ample depth. Rules that would hold good in a place like Aransas Pass with a mean tide of 14 ins. might, and in some instances undoubtedly would, be disastrous, if applied at a place like Grays Harbor, with a mean range of tide of 8.4 ft., and a tidal discharge many times that at Aransas Pass. Maj. Symons.

Prof. Haupt further says: "Sufficient data are not given in the paper to permit of a definite solution of the problem." The answer to such a criticism is, of course, sufficient data are not given for a definite solution, and it would be impossible to give sufficient data to enable an engineer 3 000 miles away and unfamiliar with local conditions to solve the problem correctly. No engineer of high standing, familiar with such works, would dream of definitely solving the problem without visiting the locality and becoming familiar with conditions which cannot all be described or depicted.

Col. Mendell summarizes in a very clear manner the great principles underlying the methods of harbor improvement on the Pacific coast. The author does not disagree with anything he says, but goes little further than he does. In regard to a single jetty, he says: "A single jetty cannot, in the general case, be said to fulfil the first condition" (control of a tidal prism for a conserving force). "At most, it does a partial service. It is good as far as it goes. It limits the azimuth of variation in channel alignment, but does not determine a single channel." This is undoubtedly true, but there may be in addition to a single jetty natural forces acting with unvarying regularity, which in connection with a single jetty, determine, develop and maintain a suitable and sufficient channel. This is the case at Columbia River and at Coos Bay, and the author believes that it will be found to be the case at Grays Harbor. Why, then, should the invariable rule be adopted of providing double jetties, when nature has provided a substitute for one of them? The author's contention is that works should be planned so as to take advantage of the natural tendencies of the channels, so that, if possible, the desired results can be accomplished with one jetty. The way is always open to supplement this afterward with another jetty, if a more complete conservation of the tidal forces is necessary.

Captain Abbot, in his opening paragraph, states clearly the fundamental principle which must govern in any successful attempt to control such gigantic forces as those existing at the entrance to Grays Harbor, viz.: "Interfere with existing conditions just enough to produce the desired local effect, but not enough to produce such extensive changes as to introduce new and unknown factors into the indeterminate equations between the forces tending to close up and those tending to deepen and enlarge the entrance."

The points mentioned by Captain Abbot, as well as many others, were considered in the location of the jetty. Captain Abbot says "the

Maj. Symons. cost is greatly affected by the depth in which the jetty is built, so that the configuration of the present bottom must be considered in addition to all other factors that enter into the study." While this is true to a limited degree, it is in reality not as important as it appears to be. It is found in practice that as soon as the jetty is pretty well out, that the sand scours away from its front, making a cross channel of approximately the same depth as the deepest water near it. The construction starts at the bottom of this cross channel. This scour can be regulated to a certain extent by the order of the work, but it is generally considered best to let it take place to a considerable degree in order to put the foundation of the jetty at a reasonably safe depth.